

# Physiology and the Acquisition of Phonology<sup>1</sup>

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1. In this paper I shall extend to the acquisition process my earlier discussion (Drachman 1970a) concerning the relationship between phonological rules and the physiology of speech production. In that paper I showed that the response of the tract to the demands of a finely detailed and language-specific rule-system was to initiate certain global configurations and timing relationships, which I identified with the classical notion the 'Basis of Articulation', so as to guarantee ease of articulation to the real-time rule-guided processes of speech production for the language concerned. In summary I concluded that, for the mature language speaker, the tract has come to terms with the rule system.

What I want to examine here, on the other hand, is how the content of the rules for the earliest stages of phonological acquisition is itself at least partly dictated by the speed and ease with which certain muscle coordinations (in their paradigm and sequence relationships within a language) are mastered by the developing child. To the extent that this proves true, the tract may be said to dominate the rules--for the time period concerned.

I shall outline a simple model for the maturation of articulatory control, and suggest how such a model may capture the facts for at least the earliest stages of acquisition. It is a very primitive model, so far solving only a few of the problems--but it is only meant to be suggestive, or at most programmatic.

2. From the co-articulation studies of Öhman (1966), the cineradiographic studies of Perkell (1969), and the computer-simulation studies in Lindblom and Sundberg (1969), the following simplified three-part model for adult articulatory control emerges.

First, there is a functional division of articulatory activity into two overlapping classes: vowel articulation is accomplished mainly by the large, slow-moving extrinsic tongue muscle system--controlling gross tongue position; on the other hand, consonant articulation requires not only this first system but also the superimposition of the smaller, faster-moving and more complex intrinsic system of tongue muscles--controlling local tongue deformation. The intrinsic tongue muscles in turn fall functionally into (at least) two groups: the one controls the raising of the tongue tip; the other, the bulging or depression of the mid-line of the tongue in the palatal, velar, or pharyngeal region.

Second, there is superimposed on this double system for positioning and deforming the tongue, an over-riding pressure consideration. At least three degrees of oral pressure are required:

for the stops a sharp, maximal increase; for the fricatives, a less extreme increase, with controlled airflow; and for the nasals, a total pressure-relief coordinating with maximum closure of the tract.<sup>2</sup>

Third, as for all skilled behavior, a feed-back control system must be added;<sup>3</sup> I propose the following mixed system, which is at least consistent with the present state of our understanding.

For the place of articulation, feed-back may be achieved mainly by tactile feedback from the contacting members. For manner of articulation, the pressure in the oral chamber may itself be monitored,<sup>4</sup> in conjunction with acoustic feedback. For the vowels, control is probably achieved through acoustic feedback, but also through the muscle-internal sensors known as spindles.<sup>5</sup>

3. The preliminary maturation model which I tentatively propose considers the mastering of an increasingly complex interaction between these three subsystems--extrinsic tongue, intrinsic tongue, and pressure-control--in conjunction with the jaw, lips and velum. The model predicts that motor control of the speech musculature as used for speech is at first gross, then fine, with respect to developmental neurophysiology,<sup>6</sup> and might well mature in the following overlapping stages for the early acquisition period.

At the first stage the tongue-extrinsic system begins to be mastered, and the pressure system is commanded only at its polar values, maximum pressure alternating with minimal pressure. On the other hand, the tongue-intrinsic musculature is not yet brought at all into relation with either the tongue-extrinsic system or the pressure system. Maximum pressure corresponds of course to stoppage; since the extrinsic system is mastered first, this involves only the jaw-lip subsystem and is achieved by ballistic impulse--giving the bilabial voiceless<sup>7</sup> stop [p]. Contrariwise, minimal pressure produces a vowel, whose quality is dictated--like the sequence alternation CV (later, CVC)--by polarity of the total extrinsic system; thus, the most peripheral stop is paralleled by the most opposed configuration<sup>8</sup> of the tongue-extrinsic system--the result is the vowel [a].

At the second stage, the tongue-intrinsic muscle-system is brought into play, but the pressure-control system remains polarized. The most mobile part of the tongue proves to be the tip and blade,<sup>9</sup> and this is indeed what is activated first within the newly developing sub-system:<sup>10</sup> its interaction with maximal pressure gives the stop [t]. The inventory of possible utterances is thus increased to [pa, ta].

At the third stage, the pressure-control parameter is diversified, though without involving finer degrees of control; mastery over the raising and lowering of the velum in coordination with oral stoppage (through either the extrinsic or limited intrinsic system) produces an oral median stop without pressure being built up in the oral chamber. The outcome is the continuously voiced [m] and [n].<sup>11</sup> Now the system is capable of [pa, ta; ma, na].

Finer control of the pressure parameter might be expected to proceed from stops to approximants, with fricatives following. Thus, we expect next the bilabial approximant [w], together with the blade approximant [y].

A still later stage must, it seems, be postulated for the achievement of the even finer command of the pressure system required for fricatives. Like the approximants, the fricatives entail controlled rather than ballistic approach of the moving articulator, but the latter to such a degree of constriction as to generate turbulent rather than laminar air-flow. For this stage should be added [f, s] and the resultant total inventory is [pt, mn, fs].

Before considering how far the ordering of the stages suggested is born out in available acquisition data, three remarks are pertinent.

First, for each set of 'places' there are relative difficulties. One example is the simple difficulty of articulating [f] until the front teeth are all present; but against this is to be balanced the fact that [s] is not at all a simple blade articulation--rather, the tongue must be grooved along its center line.

Second, not all positions in the word (or phrase) will prove to be equally difficult. If this is in any way connected with articulator-timing requirements, one might predict (for example) that nasals will first appear word initially, rather than medially or finally. Despite the fact that the velum is raised as part of the speech-ready configuration, it is also clear that an initial nasal partly inhibits velum raising.<sup>12</sup>

Third, there are global qualities of utterances (at this stage, probably single words) such as the assimilatory dominance of voicing. This is probably to be associated with the absolute dominance of the vowel-gesture (on which consonants are superimposed); and results in a tendency for all pre-vocalic consonants to be lax:<sup>13</sup> while the opposed trend, to assimilate to the following voicelessness of non-speech breathing, is equally seen for final consonants.

4. How far, now, does the above account correspond to known facts concerning acquisition?

First, the polar functions of muscle and pressure systems correlate with the systemic oppositions of Jakobson's (1968) account, for which they in fact supply a physiological basis. Thus, for example, the notion of a segment with maximal oral pressure (a stop) opposed to one with minimal pressure (say, a low back vowel) has physiological as well as systemic priority.<sup>14</sup>

Second, the ordering of (my) second and third stages shows some alternation in the data. Jakobson (1968) holds that the first consonantal opposition is that of the nasal and oral stop, which is followed by the opposition of labials and dentals. I have, on the other hand, suggested that the intrinsic tongue system is already active before the pressure control is diversified. But note that from the point of view of physiological complexity, the added complications are somewhat equal--so that some children master

the velum co-ordination before bringing the tongue-intrinsic system into play, However, in Velten (1943) and Leopold (1947) we have the chronological sequence [p - t, then m - n] here predicted.<sup>15</sup>

The comparatively late appearance of fricatives is predicted by both Jakobson and the present account; again, one systemic and physiological grounds respectively. Joan Velten, however, had [pts] within 13 months, [f] at 14 months, but no nasal until 17 months: still more irregularly, Hildegard Leopold first shows a spirant [s̥] not only before the appearance of [t] in the same position (finally), but also before the appearance of [n] in any position.

Both the Velten and the Leopold data suggest that the CV pattern is first broken, and CVC established as a unit of production, with final spirants<sup>16</sup>--and it is in final position that the acquisition-ordering irregularity occurs. Synchronic and diachronic studies concerning loss of final consonantisms support the conclusion that it is the syllable (and thus word) position constraint that is important here, rather than the abstract notion 'inventory'.

The appearance of the palatal spirant [s̥] in final position (Leopold) presents an interesting puzzle. First, [s̥] at 17 months is found only as a substitute for final [s]--underlying [s] being still deleted at this stage. Note that the common substitute for initial [s] at the same stage is [j], also palatal; thus, in the maturation model, for a production unit type CVC, the pressure-control parameter comes under fine control earlier for the final than for the initial segment.<sup>17</sup> If we add to this the prediction that tongue grooving will present special problems, and that some children will thus prefer a non-grooved spirant,<sup>18</sup> we account for the fact that the [s]-substitute in initial position may be the approximant [h]--corresponding to [s] itself; or, it may be a fricative [j]--fairly closely corresponding to the non-grooved alternant substitute [s̥].

5. I have supposed that during acquisition the child is experimenting in his search for a set of physiological mechanisms by which he may best represent and reproduce the structures inferrable from the speech he hears around him. But the model I outlined initially quickly proves to be somewhat rigid and simplistic, and even the samples of data I have cited show clearly that there will be a range of available strategies for each stage. But it is also reasonable to claim that the range of strategies that proves to be available at different stages is at least partly dictated by the maturing ability to command and integrate the appropriate physiological sub-systems.

## Footnotes

1. A fuller version of the present paper was originally read at the LSA meeting, July 1970. I wish to acknowledge the helpful commentary of Harry Whitaker, as a result of which a number of important points in this paper were clarified or amplified during 1970. However, for this publication (1973), I present only the first half of the paper; this gives the model itself, but only a hint (section 4) as to how well it explicates known acquisition data.

2. The laterals seem to require the same degree of pressure-relief as the nasals, vowels and semi-vowels. In my view, the notion "force of articulation" is at least partly to be accounted for in terms of oral pressure, the "force" being necessary to contain a given pressure, and giving rise in turn to (e.g.) longer closure for voiceless than for voiced stops.

3. The 'bias', or feed-forward system involves an additional set of priming features clearly related to the 'Basis of Articulation'.

4. Malecot's (1966) experiments (unfortunately not yet replicated for young children) suggest that subjects are sensitive to oral pressure differences as small as those obtaining during normal speech. It is possible that place of stop-articulation is also 'confirmed' via the spindles, since it is known (Houde, 1968) that tongue-deformation during the closure for stops correlates with intra-oral pressure.

5. Cf. the review of non-acoustic feedback mechanisms in Hardcastle (1970). Whitaker points out (personal communication) that of course of the three types of feedback, acoustic feedback applies to the output of the entire tract, whereas proprioceptive and tactile feedback apply only to parts of it. Even more suggestive is his remark that this distinction may correspond to that between a cortical (acoustic) and a purely brain-stem (the rest) type of feedback loop.

6. One would expect corroborative evidence from the neurological sciences for such a notion, as regards not only the motor commands, but also those for feed-forward (anticipatory) and feed-back. For doubts on the role of proprioception see also MacNeilage (1970) and for outright scepticism Konorski (1967), and Wickelgren (1969).

7. The oral pressure condition naturally results in voicelessness for obstruents (cf. Halle and Stevens 1967). For the state of the velum, up is unmarked--since this is part of speech-ready 'priming' (i.e.. part of the Basis of Articulation) and probably a universal element.

8. Reciprocal innervation is perhaps the neurological correlate to "opposed configuration".

9. See Cooper (1953), Dixon (1961).

10. Feedback, both tactual and proprioceptive, is richer for the front of the tongue than for the rest of the oral region (or, for that matter, the whole of the rest of the body (Cf. Dixon 1961)).

11. The other continuously voiced oral median stop is the lateral [l], the added complications concerning which I discuss elsewhere ("A note on the Acquisition of [l]," mimeo, 1970b).

12. This may be seen in the nasal sonde recordings in Kozhevnikov and Chistovich (1965).

13. As the data in Leopold (1947) suggest, this also results in a tendency for unstressed vowels to assimilate to preceding stressed ones.

14. Note that the present account does not necessarily predict [p] as the 'first' consonant, although of course it does not preclude it either.

15. Tantalizing is the fact that from 13 months to 19 months, Hildegard Leopold attempted no words with initial [t]--in fact, until both nasals were in her inventory!

16. It is surely relevant that the first clusters are not only also found finally, but also involve [s], as in Velten's [uts] for 'cats' and [futs] for 'fix' (22 months).

17. This does not of course account for the absence of final stop [t] at a stage where final spirants are present.

18. The account here emphasizes, while not solving, the general problem of why a child may be unable to produce a given sound, and yet able to produce it as a substitute for an other sound. I shall take up elsewhere the question whether the 'substitute' is in fact homologous for articulation with the adult model.

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